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# THERMAL CONDUCTIVITY OF GLASS FIBER/EPOXY COMPOSITE SUPPORT BANDS FOR CRYOGENIC DEWARS, PHASE II

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National Bureau of Standards  
U.S. Department of Commerce  
Boulder, Colorado 80303

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# **THERMAL CONDUCTIVITY OF GLASS FIBER/EPOXY COMPOSITE SUPPORT BANDS FOR CRYOGENIC DEWARs, PHASE II**

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March 1984

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NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director



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The thermal conductivities of three specimens of glass fiber/epoxy composites were measured and reported for the temperature range 4 to 300 K. These specimens were fabricated from two cryogenic dewar support bands. An average conductivity curve for the three specimens is presented. The data for the three specimens are within  $\pm 5\%$  of this average curve. The average curve is compared to a similar curve obtained five years ago in Phase I of this continuing study of composite materials.

Key words: composite; epoxy; glass fiber; low temperature; thermal conductivity

## 1. INTRODUCTION

Composite materials have significant advantages in applications requiring high strength and low thermal conduction. As a consequence, the National Bureau of Standards has been researching the mechanical and thermal properties of composites used in technological applications.

The purpose of this study is to measure the thermal conductivity of several composite specimens fabricated from actual cryogenic support bands. These data, in addition to being valuable for general composite characterization, will be used to calculate the support band portion of the heat leak into an in-flight liquid helium dewar.

## 2. MATERIAL AND SPECIMEN CHARACTERIZATION

This report provides thermal conductivity data on two filament wound glass fiber/epoxy support bands. The bands are used as support members for the superfluid helium dewar to be used in the Cosmic Background Explorer (COBE) Observatory. Three specimens were fabricated from these bands by sectioning the straps. The cut pieces were epoxied together to form the final specimens measured. The characteristics of these specimens are given in Table 1.

Additional fabrication and characterization details can be found in the report of Phase I of this work by Hust and Arvidson (1978). The supplier of these bands has indicated that the fabrication materials and procedures are very similar to the previously measured bands. It is noted, however, that the above densities of the new bands are about 4% lower than those measured previously. The densities previously measured (four specimens) ranged from 2.09 to 2.12 g/cm<sup>3</sup>. Also the coloration of the two sets is considerably different. The bands measured in 1978 are dark brown, while the current bands are amber.

One additional difference between the current specimens and those previously measured is the thickness. It has been found that the optimum accuracy for this apparatus with low conductivity specimens is obtained at a lower thickness than



Table 1. Characteristics of Specimens

Part Number	Band Serial Number	Specimen Number	Specimen Dimensions (cm)			Weight (g)	Density (g/cm <sup>3</sup> )
			Thickness	Width A	Width B		
151490-1	25A	25-A	0.540	1.879	1.737	3.562	2.02
151490-1	25A	25-B	0.644	1.920	1.735	4.358	2.03
151490-1	26	26	0.540	1.905	1.798	3.707	2.00

The fibers are S-2 glass (essentially the same as MIL SPEC S901) and the resin is SCI REZ 081. (The previously used resin is SCI REZ 080). The use of trades is necessary for material identification. No endorsement or approval of the product is intended.

previously used. The thickness is in the direction of the fibers and in the direction of the measured heat flow. The previous specimens were measured at about 2.4 cm thickness, while these at about 0.6 cm thickness. In Table 1, the width (A) is parallel to the pieces cut from the strap while width B is perpendicular to the pieces (both are perpendicular to the glass fibers and heat flow). Previous measurements on similar composites indicate that this change in form factor should not affect the results of these measurements beyond the stated uncertainty.

### 3. EXPERIMENTAL PROCEDURE AND DATA ANALYSIS

The measurements on the test specimens are performed in an apparatus previously described by Hust and Arvidson (1978). The accuracy, based on considerable experience with this apparatus, including the measurement of Standard Reference Materials, is given as 10%. The imprecision of the data has been found to be near 1% for a given specimen mounting and no more than 5% for specimen remounting in the apparatus.

The experimental data are actually thermal conductivity integral values, since large temperature differences are used. The methods used to analyze these data to obtain thermal conductivity values are described by Hust and Lankford (1982). It is to be noted that the differences between the values obtained by the usual difference technique and the values obtained by the thermal conductivity integral technique are quite small because of the monotonic nature of the curve for this material.

### 4. RESULTS AND DISCUSSION

The direct experimental data for the three specimens are presented in the appendix. These data were analyzed by both the difference method and the thermal conductivity integral method. The results of these calculations for all of the data are illustrated in Fig. 1. The function chosen for the integral method is



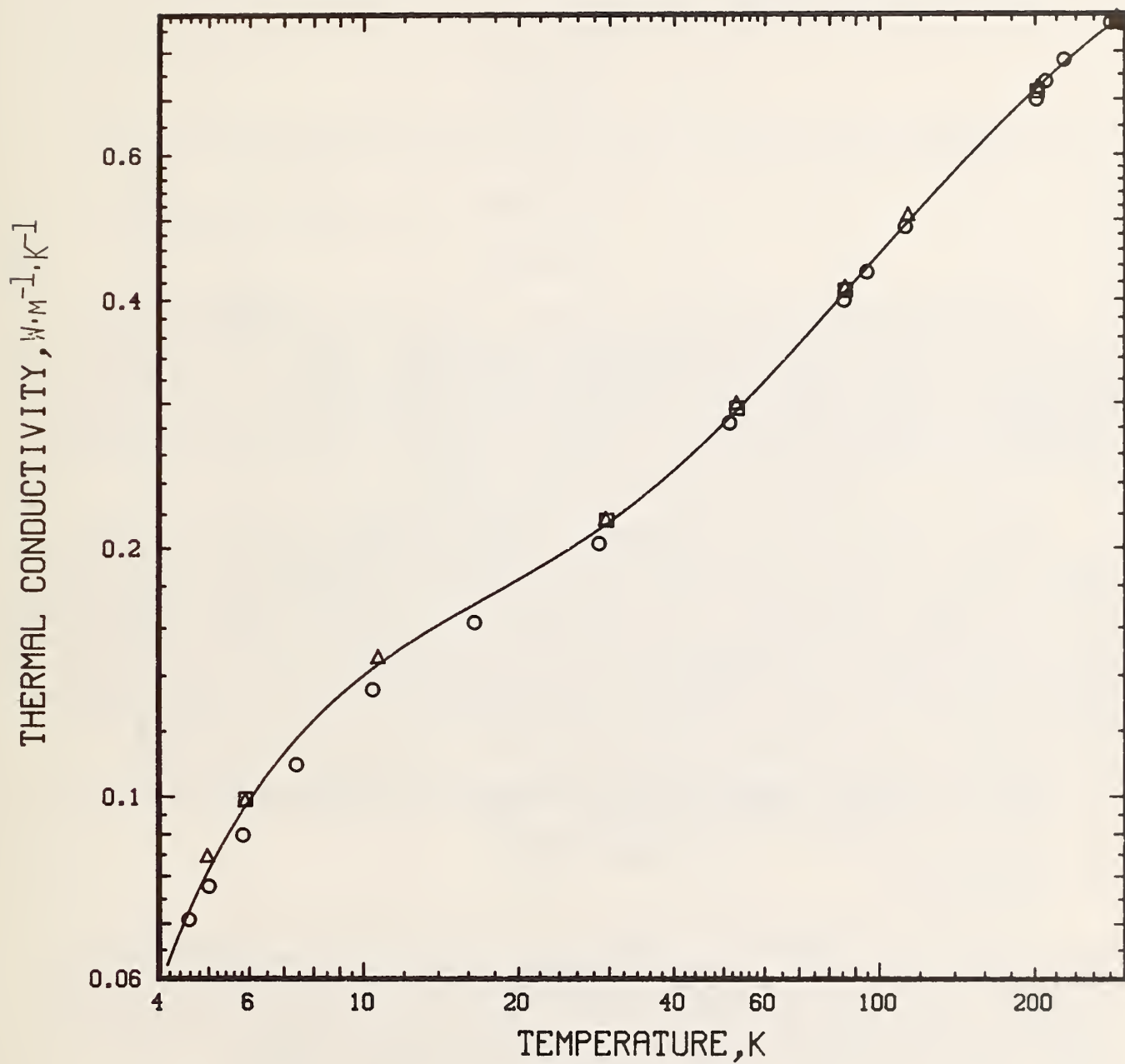


Figure 1. Thermal conductivity of glass fiber/epoxy composite support bands, present measurements.

○ = Specimen 25-B  
 ▲ = Specimen 25-A  
 □ = Specimen 26

} From difference method.  
 Solid line = values from equation 1

$$K(T) = \sum_{i=1}^5 A_i [\ln(T+1)]^i \quad (1)$$

where  $K(T)$  is thermal conductivity,  $T$  is temperature in Kelvin, and the  $A_i$  resulting from the least squares fit are:

$$A_1 = -0.30274718$$

$$A_2 = 0.43272669$$

$$A_3 = -0.18794186$$

$$A_4 = 0.034528862$$

$$A_5 = -0.0021756062$$

The deviations of the measured thermal conductivity integrals from those calculated from (1) are illustrated in Fig. 2. As can be seen, these three specimens are nearly the same in thermal conductivity. However, the differences are somewhat larger than for the specimens measured previously. The current differences are  $\pm 5\%$  from the mean at low temperatures, decreasing to  $\pm 1\%$  at higher temperatures. The previous results showed differences of about  $\pm 2\%$  from the mean at low temperatures and  $\pm 4\%$  at higher temperatures.

More important are the differences between the means of the two sets of measurements. Figures 3 and 4 compare the two sets of data. The present values differ from the earlier results by as much as 27% at low temperatures, decreasing to 7% at higher temperatures. The reason for this difference is not understood. It may be connected with the observed difference in density referred to earlier. The thickness difference between the two sets of specimens may be partly responsible for the difference. However, it is noted that Kapitza resistance differences should not be effective to such high temperatures, and the ordinary radiative thickness effect should be most effective at the higher temperatures.

Table 2 contains values of thermal conductivity as calculated from eq. (1) for the present specimens.

## 5. ACKNOWLEDGMENTS

The author acknowledges the support of Dr. Steve Castles of the Goddard Space Flight Center, NASA. Also acknowledged is Structural Composite Industries for supplying the material and characterization data. Finally I thank Richard Hopkins of Ball Aerospace Systems Division (BASD) for expediting specimen acquisition and miscellaneous interactions with the sponsor and supplier. BASD is under contract to build the helium dewar for the COBE Observatory.

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Hust, J. G. and Arvidson, J. M., Thermal Conductivity of Glass Fiber/Epoxy Composite Support Bands for Cryogenic Dewars, Report 275.03-78-2, 80 pages, 1978.

Hust, J. G. and Lankford, A. B., Comments on the Measurement of Thermal conductivity and Presentation of a Thermal Conductivity Integral Method, International Journal of Thermophysics, Vol. 3, No. 1, 67-77 (1982).

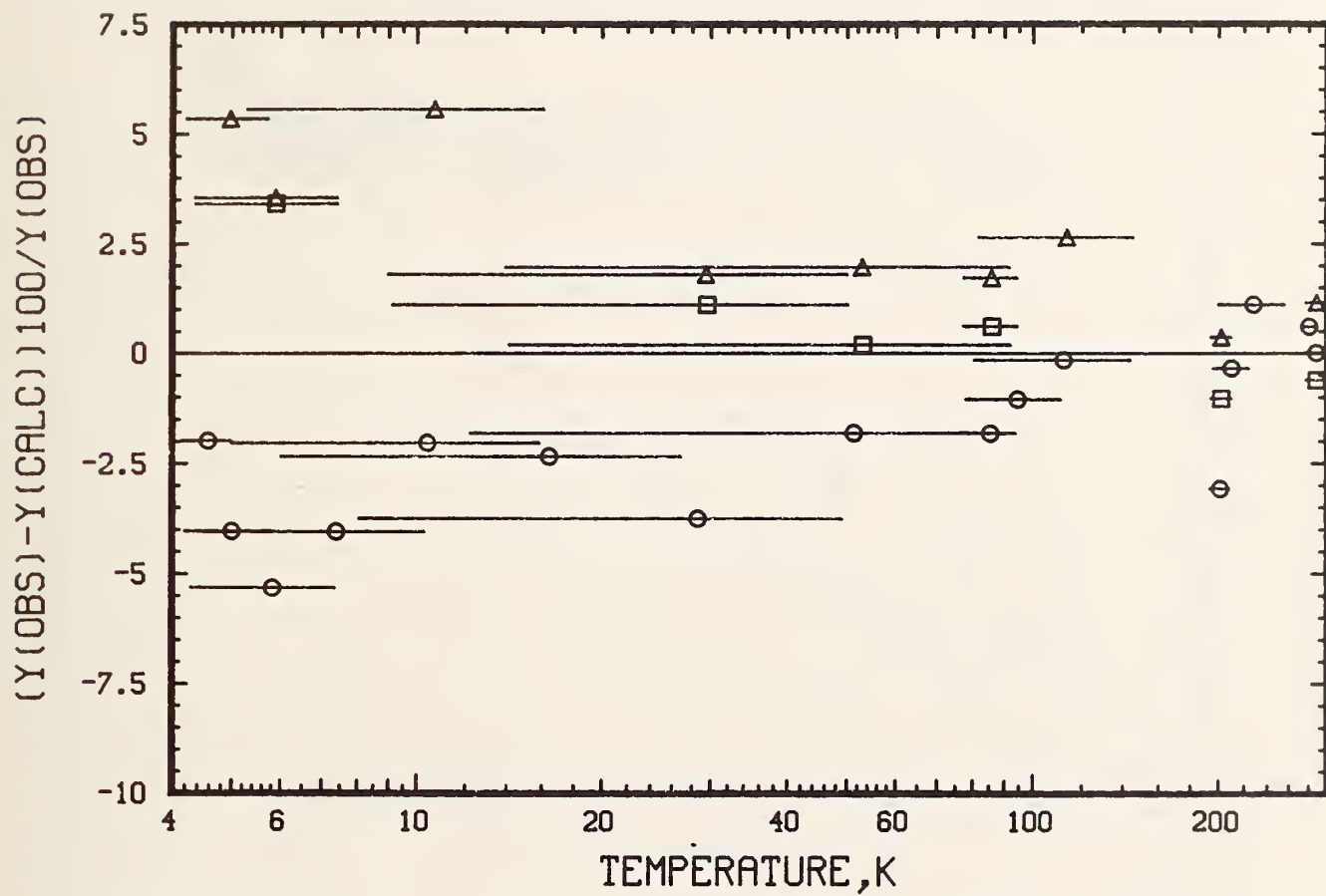


Figure 2. Deviations of observed thermal conductivity integrals from those calculated with equation 1. The horizontal bars indicate the temperature span of the measurement for glass fiber/epoxy composite support bands.

○ = Specimen 25-B  
 ▲ = Specimen 25-A  
 □ = Specimen 26

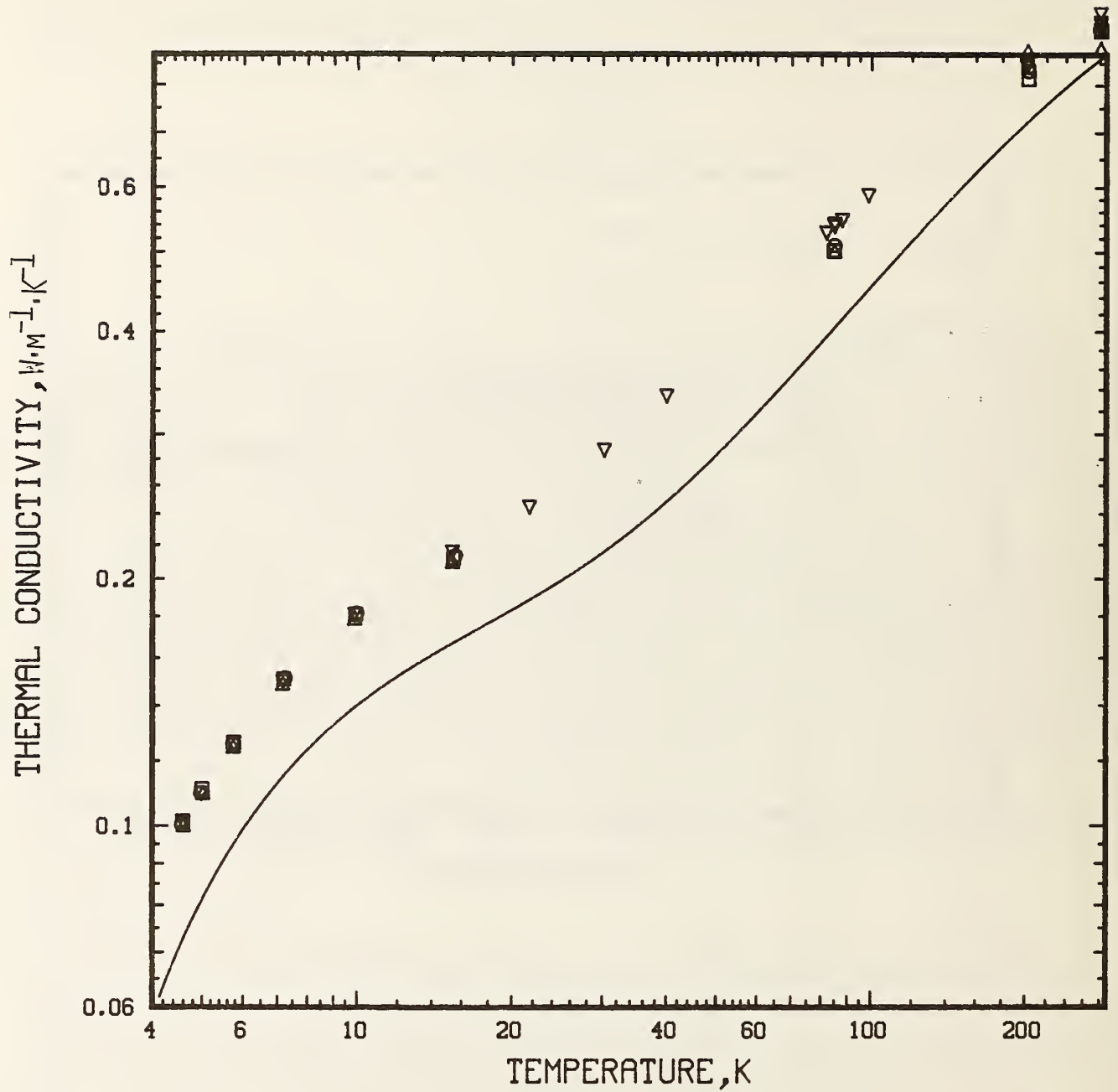


Figure 3. Comparison of current results to those obtained in 1978 for glass fiber/epoxy composite support bands.

Discrete symbols = 1978 results on four specimens  
 Solid line = current results

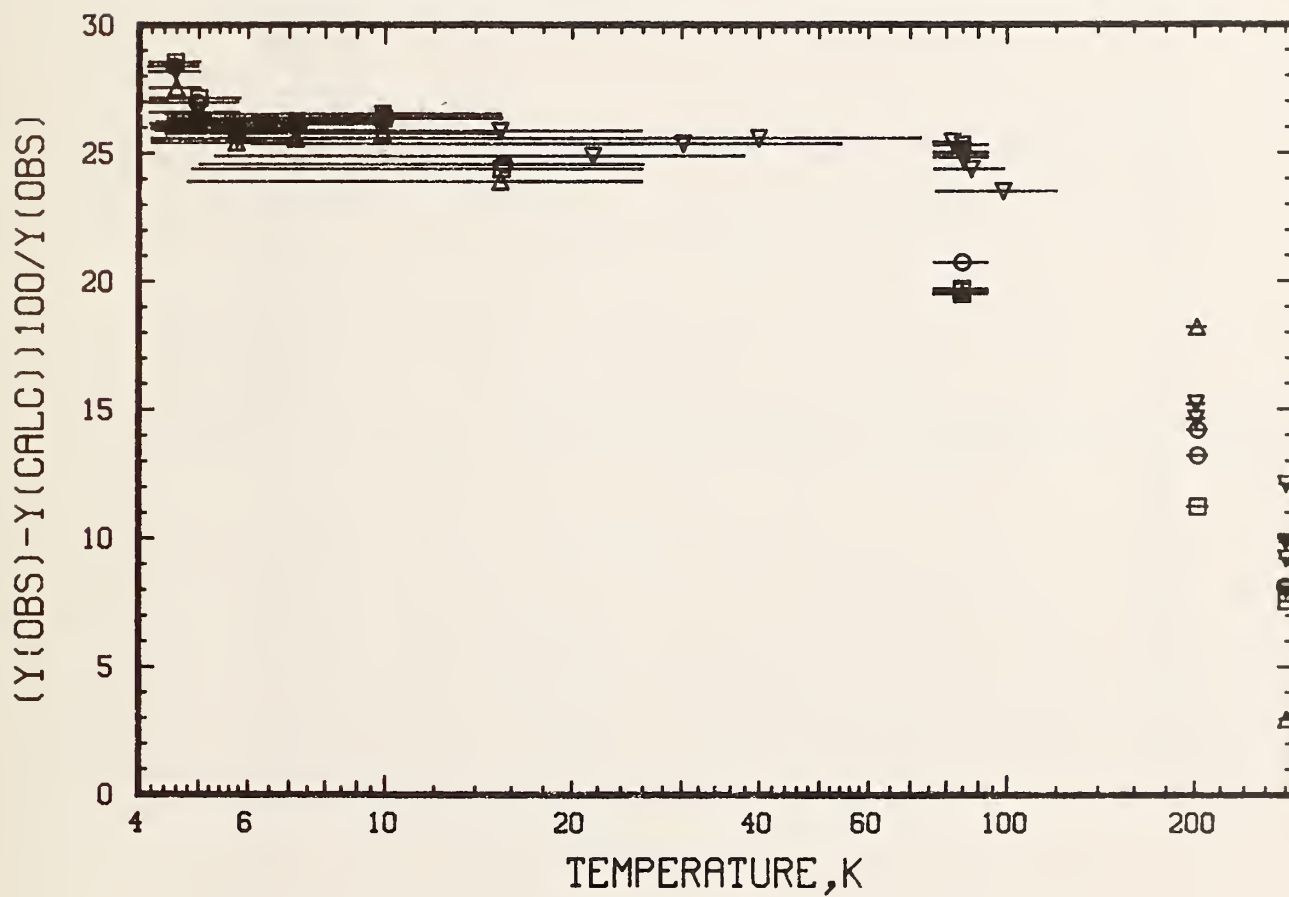


Figure 4. Deviations of 1978 thermal conductivity integrals from values calculated with equation 1 using current coefficients for glass fiber/epoxy composite support bands.

Table 2. Thermal Conductivity Values for the Combined Glass Fiber/Epoxy Composite Support Bands of this Research as Calculated from Equation 1.

Temperature (K)	Thermal Conductivity (W.m <sup>-1</sup> .K <sup>-1</sup> )
4	0.0584
5	0.0814
6	0.0990
8	0.124
10	0.140
15	0.165
20	0.183
30	0.215
40	0.248
50	0.285
60	0.318
80	0.388
100	0.454
150	0.600
200	0.719
300	0.890

## APPENDIX

### Direct Experimental Data

For potential future reference it is desirable to record the direct experimental data. These data along with some pertinent calculated quantities are recorded in the following format for each run:

1st line - specimen identification, data, time

2nd line - variable identification

3rd line - variable values

Remaining lines are identified - thermal conductivity is expressed in  $\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ .

Abbreviations in the 2nd line have the following meaning:

HTR VOLT = voltage across heater in volts

HTR CURR = current through heater in milliamps

DELTA E = Emf of differential thermocouple between blocks in microvolts

BTH = code indicating the cryogen

= 1. = liquid helium

= 2. = liquid hydrogen

= 3. = liquid nitrogen

= 4. = dry ice - alcohol mixture

= 5. = ice - water mixture

PRB = code indicating the probe

= 1. = bonded probe

= 2. = compression probe

DIAMETER = equivalent diameter for specimen cross-section in centimeters

TEMP = cryogen temperature in Kelvins

DELE ZERO = spurious emf of differential thermocouple at zero power from heater in microvolts

DELTA X = specimen length in centimeter



# APPENDIX (continued)

## Specimen 25-B

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/7/83,1400

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
8.5277	42.8800	299.17	3.	2.	1.9690	76.00	0.00	.5439

THERMAL CONDUCTIVITY= .3988E+00 UNCERTAINTY= 5. PERCENT  
 AT A MEAN TEMP OF 85.316  
 WITH BLOCK TEMPS OF 93.695 AND 76.936 DELT= 16.760  
 HERE TOTAL HEAT FLOW= .3657E+00 AND SPEC HEAT FLOW= .3161E+00( 86. PCT)  
 Q/T,DELT(TOTAL)= .2557E-03 (EMPTY PROBE)= .3469E-04 (SPECIMEN)= .2210E-03  
 HEATER RESISTANCE= 198.874 AND HEATER VOLTAGE= .8528E+01

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/7/83,1530

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
12.4213	62.4680	600.21	3.	2.	1.9690	76.00	0.00	.5439

THERMAL CONDUCTIVITY= .4314E+00 UNCERTAINTY= 5. PERCENT  
 AT A MEAN TEMP OF 94.432  
 WITH BLOCK TEMPS OF 110.877 AND 77.986 DELT= 32.891  
 HERE TOTAL HEAT FLOW= .7759E+00 AND SPEC HEAT FLOW= .6710E+00( 86. PCT)  
 Q/T,DELT(TOTAL)= .2498E-03 (EMPTY PROBE)= .3377E-04 (SPECIMEN)= .2161E-03  
 HEATER RESISTANCE= 198.843 AND HEATER VOLTAGE= .1242E+02

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/7/83,1730

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
18.3937	92.4430	1199.70	3.	2.	1.9690	76.00	0.00	.5439

THERMAL CONDUCTIVITY= .4896E+00 UNCERTAINTY= 5. PERCENT  
 AT A MEAN TEMP OF 112.062  
 WITH BLOCK TEMPS OF 143.770 AND 80.353 DELT= 63.417  
 HERE TOTAL HEAT FLOW= .1700E+01 AND SPEC HEAT FLOW= .1468E+01( 86. PCT)  
 Q/T,DELT(TOTAL)= .2393E-03 (EMPTY PROBE)= .3266E-04 (SPECIMEN)= .2066E-03  
 HEATER RESISTANCE= 198.973 AND HEATER VOLTAGE= .1839E+02

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/8/83,1255

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
.7701	3.8740	9.98	1.	2.	1.9690	4.02	-.30	.6439

THERMAL CONDUCTIVITY= .7081E-01 UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 4.577  
 WITH BLOCK TEMPS OF 4.996 AND 4.158 DELT= .838  
 HERE TOTAL HEAT FLOW= .2983E-02 AND SPEC HEAT FLOW= .2807E-02( 94. PCT)  
 Q/T,DELT(TOTAL)= .7776E-03 (EMPTY PROBE)= .4587E-04 (SPECIMEN)= .7317E-03  
 HEATER RESISTANCE= 198.787 AND HEATER VOLTAGE= .7701E+00

# APPENDIX (continued)

## Specimen 25-B

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIR STRAP 25-B,6/8/83,1305

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	OELE ZERO	DELTA X
1.1188	5.6300	19.99	1.	2.	1.9690	4.02	-.30	.6439

THERMAL CONDUCTIVITY= .7776E-01      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 5.005  
 WITH BLOCK TEMPS OF 5.811 AND 4.199 DELT= 1.612  
 HERE TOTAL HEAT FLOW= .6299E-02 AND SPEC HEAT FLOW= .5928E-02( 94. PCT)  
 Q/T,DELT(TOTAL)= .7806E-03 (EMPTY PROBE)= .4594E-04 (SPECIMEN)= .7347E-03  
 HEATER RESISTANCE= 198.721 AND HEATER VOLTAGE= .1119E+01

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIR STRAP 25-B,6/8/83,1320

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	OELE ZERO	DELTA X
1.6587	8.3520	39.95	1.	2.	1.9690	4.02	-.30	.6439

THERMAL CONDUCTIVITY= .8986E-01      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 5.827  
 WITH BLOCK TEMPS OF 7.360 AND 4.294 DELT= 3.066  
 HERE TOTAL HEAT FLOW= .1385E-01 AND SPEC HEAT FLOW= .1303E-01( 94. PCT)  
 Q/T,DELT(TOTAL)= .7754E-03 (EMPTY PROBE)= .4612E-04 (SPECIMEN)= .7293E-03  
 HEATER RESISTANCE= 198.599 AND HEATER VOLTAGE= .1659E+01

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/8/83,1335

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	OELE ZERO	DELTA X
2.5136	12.6600	79.99	1.	2.	1.9690	4.02	-.30	.6439

THERMAL CONDUCTIVITY= .1094E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 7.398  
 WITH BLOCK TEMPS OF 10.283 AND 4.514 DELT= 5.769  
 HERE TOTAL HEAT FLOW= .3182E-01 AND SPEC HEAT FLOW= .2984E-01( 94. PCT)  
 Q/T,DELT(TOTAL)= .7456E-03 (EMPTY PROBE)= .4653E-04 (SPECIMEN)= .6991E-03  
 HEATER RESISTANCE= 198.547 AND HEATER VOLTAGE= .2514E+01

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIR STRAP 25-B,6/8/83,1350

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	OELE ZERO	DELTA X
3.8392	19.3400	159.93	1.	2.	1.9690	4.02	-.30	.6439

THERMAL CONDUCTIVITY= .1346E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 10.413  
 WITH BLOCK TEMPS OF 15.823 AND 5.003 DELT= 10.819  
 HERE TOTAL HEAT FLOW= .7425E-01 AND SPEC HEAT FLOW= .6889E-01( 93. PCT)  
 Q/T,DELT(TOTAL)= .6590E-03 (EMPTY PROBE)= .4758E-04 (SPECIMEN)= .6115E-03  
 HEATER RESISTANCE= 198.511 AND HEATER VOLTAGE= .3839E+01

# APPENDIX (continued)

## Specimen 25-B

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/8/83,1410

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	OIAMETER	TEMP	OELE ZERO	DELTA X
5.9210	29.8220	319.95	1.	2.	1.9690	4.02	-.30	.6439

THERMAL CONDUCTIVITY= .1622E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 16.431  
 WITH BLOCK TEMPS OF 26.844 AND 6.017 DELT= 20.827  
 HERE TOTAL HEAT FLOW= .1766E+00 AND SPEC HEAT FLOW= .1598E+00( 90. PCT)  
 O/T.OELT(TOTAL)= .5160E-03 (EMPTY PROBE)= .4910E-04 (SPECIMEN)= .4669E-03  
 HEATER RESISTANCE= 198.545 AND HEATER VOLTAGE= .5921E+01

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/8/83,1430

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	OIAMETER	TEMP	OELE ZERO	DELTA X
9.4112	47.3700	639.92	1.	2.	1.9690	4.02	-.30	.6439

THERMAL CONDUCTIVITY= .2023E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 28.591  
 WITH BLOCK TEMPS OF 49.121 AND 8.061 DELT= 41.059  
 HERE TOTAL HEAT FLOW= .4458E+00 AND SPEC HEAT FLOW= .3928E+00( 88. PCT)  
 O/T.OELT(TOTAL)= .3798E-03 (EMPTY PROBE)= .4517E-04 (SPECIMEN)= .3346E-03  
 HEATER RESISTANCE= 198.674 AND HEATER VOLTAGE= .9411E+01

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/8/83,1520

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	OIAMETER	TEMP	OELE ZERO	DELTA X
15.4600	77.7600	1280.14	1.	2.	1.9690	4.02	-.30	.6439

THERMAL CONDUCTIVITY= .2835E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 51.255  
 WITH BLOCK TEMPS OF 90.272 AND 12.238 DELT= 78.034  
 HERE TOTAL HEAT FLOW= .1202E+01 AND SPEC HEAT FLOW= .1046E+01( 87. PCT)  
 O/T.OELT(TOTAL)= .3006E-03 (EMPTY PROBE)= .3899E-04 (SPECIMEN)= .2616E-03  
 HEATER RESISTANCE= 198.817 AND HEATER VOLTAGE= .1546E+02

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/9/83,920

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	OIAMETER	TEMP	OELE ZERO	DELTA X
10.7195	53.8300	306.97	4.	2.	1.9690	192.00	0.00	.6439

THERMAL CONDUCTIVITY= .6991E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 200.991  
 WITH BLOCK TEMPS OF 208.210 AND 193.771 DELT= 14.439  
 HERE TOTAL HEAT FLOW= .5770E+00 AND SPEC HEAT FLOW= .4773E+00( 83. PCT)  
 O/T.OELT(TOTAL)= .1988E-03 (EMPTY PROBE)= .3435E-04 (SPECIMEN)= .1645E-03  
 HEATER RESISTANCE= 199.136 AND HEATER VOLTAGE= .1072E+02

# APPENDIX (continued)

## Specimen 25-B

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/9/83,1155

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
15.3225	76.9400	599.62	4.	2.	1.9690	192.00	0.00	.6439

THERMAL CONDUCTIVITY= .7357E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 209.627  
 WITH BLOCK TEMPS OF 223.635 AND 195.619 DELT= 28.015  
 HERE TOTAL HEAT FLOW= .1179E+01 AND SPEC HEAT FLOW= .9747E+00( 83. PCT)  
 Q/T,DELT(TOTAL)= .2007E-03 (EMPTY PROBE)= .3477E-04 (SPECIMEN)= .1660E-03  
 HEATER RESISTANCE= 199.149 AND HEATER VOLTAGE= .1532E+02

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/9/83,1515

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
22.3430	112.2000	1200.50	4.	2.	1.9690	192.00	0.00	.6439

THERMAL CONDUCTIVITY= .7808E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 227.421  
 WITH BLOCK TEMPS OF 255.145 AND 199.696 DELT= 55.449  
 HERE TOTAL HEAT FLOW= .2507E+01 AND SPEC HEAT FLOW= .2047E+01( 82. PCT)  
 Q/T,DELT(TOTAL)= .1988E-03 (EMPTY PROBE)= .3644E-04 (SPECIMEN)= .1624E-03  
 HEATER RESISTANCE= 199.135 AND HEATER VOLTAGE= .2234E+02

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/10/83,1110

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
10.7640	54.0000	239.15	5.	2.	1.9690	273.20	0.00	.6439

THERMAL CONDUCTIVITY= .8661E+00      UNCERTAINTY= 5. PERCENT  
 AT A MEAN TEMP OF 279.941  
 WITH BLOCK TEMPS OF 285.329 AND 274.554 DELT= 10.774  
 HERE TOTAL HEAT FLOW= .5813E+00 AND SPEC HEAT FLOW= .4413E+00( 76. PCT)  
 Q/T,DELT(TOTAL)= .1927E-03 (EMPTY PROBE)= .4641E-04 (SPECIMEN)= .1463E-03  
 HEATER RESISTANCE= 199.333 AND HEATER VOLTAGE= .1076E+02

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-B,6/10/83,1345

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
15.8097	79.3500	505.90	5.	2.	1.9690	273.20	0.00	.6439

THERMAL CONDUCTIVITY= .8718E+00      UNCERTAINTY= 5. PERCENT  
 AT A MEAN TEMP OF 287.516  
 WITH BLOCK TEMPS OF 298.910 AND 276.123 DELT= 22.787  
 HERE TOTAL HEAT FLOW= .1254E+01 AND SPEC HEAT FLOW= .9394E+00( 75. PCT)  
 Q/T,DELT(TOTAL)= .1915E-03 (EMPTY PROBE)= .4809E-04 (SPECIMEN)= .1434E-03  
 HEATER RESISTANCE= 199.240 AND HEATER VOLTAGE= .1581E+02

# APPENDIX (continued)

## Specimen 25-A

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-A, 6/13/83, 1118

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	OELE ZERO	OELTA X
1.2635	6.3600	18.53	1.	2.	2.0380	4.02	-.33	.5400

THERMAL CONDUCTIVITY= .8483E-01      UNCERTAINTY= 3. PERCENT  
 AT A MEAN TEMP OF 4.972  
 WITH BLOCK TEMPS OF 5.722 AND 4.221 DELT= 1.501  
 HERE TOTAL HEAT FLOW= .8036E-02 AND SPEC HEAT FLOW= .7593E-02 ( 96. PCT)  
 Q/T.OELT(TOTAL)= .1077E-02 (EMPTY PROBE)= .4593E-04 (SPECIMEN)= .1031E-02  
 HEATER RESISTANCE= 198.666 AND HEATER VOLTAGE= .1264E+01

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-A, 6/13/83, 1135

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	OELE ZERO	OELTA X
1.9521	9.8300	40.00	1.	2.	2.0380	4.02	-.33	.5400

THERMAL CONDUCTIVITY= .9922E-01      UNCERTAINTY= 3. PERCENT  
 AT A MEAN TEMP OF 5.891  
 WITH BLOCK TEMPS OF 7.422 AND 4.360 DELT= 3.063  
 HERE TOTAL HEAT FLOW= .1919E-01 AND SPEC HEAT FLOW= .1836E-01 ( 96. PCT)  
 Q/T.OELT(TOTAL)= .1064E-02 (EMPTY PROBE)= .4612E-04 (SPECIMEN)= .1017E-02  
 HEATER RESISTANCE= 198.586 AND HEATER VOLTAGE= .1952E+01

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-A, 6/13/83, 1145

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	OELE ZERO	OELTA X
4.4901	22.6200	160.00	1.	2.	2.0380	4.02	-.33	.5400

THERMAL CONDUCTIVITY= .1477E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 10.680  
 WITH BLOCK TEMPS OF 14.064 AND 5.295 OELT= 10.769  
 HERE TOTAL HEAT FLOW= .1016E+00 AND SPEC HEAT FLOW= .9610E-01 ( 95. PCT)  
 Q/T.OELT(TOTAL)= .8831E-03 (EMPTY PROBE)= .4757E-04 (SPECIMEN)= .8355E-03  
 HEATER RESISTANCE= 198.501 AND HEATER VOLTAGE= .4490E+01

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-A, 6/13/83, 1155

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	OELE ZERO	OELTA X
10.8462	54.5800	640.00	1.	2.	2.0380	4.02	-.33	.5400

THERMAL CONDUCTIVITY= .2171E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 29.475  
 WITH BLOCK TEMPS OF 49.965 AND 8.985 OELT= 40.980  
 HERE TOTAL HEAT FLOW= .5920E+00 AND SPEC HEAT FLOW= .5374E+00 ( 91. PCT)  
 Q/T.OELT(TOTAL)= .4901E-03 (EMPTY PROBE)= .4519E-04 (SPECIMEN)= .4449E-03  
 HEATER RESISTANCE= 198.721 AND HEATER VOLTAGE= .1085E+02



# APPENDIX (continued)

## Specimen 25-A

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-A,6/13/83,1225

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	OELE ZERO	DELTA X
17.6722	88.8800	1280.30	1.	2.	2.0380	4.02	-.33	.5400

THERMAL CONDUCTIVITY= .3000E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 52.841  
 WITH BLOCK TEMPS OF 91.744 AND 13.938 DELT= 77.806  
 HERE TOTAL HEAT FLOW= .1571E+01 AND SPEC HEAT FLOW= .1410E+01( 90. PCT)  
 Q/T.OELT(TOTAL)= .3820E-03 (EMPTY PROBE)= .3903E-04 (SPECIMEN)= .3430E-03  
 HEATER RESISTANCE= 198.832 AND HEATER VOLTAGE= .1767E+02

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-A,6/13/83,1505

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	OELE ZERO	DELTA X
9.7428	48.9900	304.40	3.	2.	2.0380	76.00	0.00	.5400

THERMAL CONDUCTIVITY= .4146E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 85.739  
 WITH BLOCK TEMPS OF 94.257 AND 77.222 DELT= 17.035  
 HERE TOTAL HEAT FLOW= .4773E+00 AND SPEC HEAT FLOW= .4267E+00( 69. PCT)  
 Q/T.OELT(TOTAL)= .3268E-03 (EMPTY PROBE)= .3468E-04 (SPECIMEN)= .2921E-03  
 HEATER RESISTANCE= 198.873 AND HEATER VOLTAGE= .9743E+01

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-A,6/13/83,1630

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	OELE ZERO	DELTA X
20.8630	104.8600	1206.60	3.	2.	2.0380	76.00	0.00	.5400

THERMAL CONDUCTIVITY= .5079E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 113.413  
 WITH BLOCK TEMPS OF 145.226 AND 81.600 DELT= 63.625  
 HERE TOTAL HEAT FLOW= .2188E+01 AND SPEC HEAT FLOW= .1952E+01( 89. PCT)  
 Q/T.OELT(TOTAL)= .3032E-03 (EMPTY PROBE)= .3265E-04 (SPECIMEN)= .2705E-03  
 HEATER RESISTANCE= 198.961 AND HEATER VOLTAGE= .2086E+02

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-A,6/14/83,925

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	OELE ZERO	DELTA X
12.3414	61.9500	320.57	4.	2.	2.0380	192.00	0.00	.5400

THERMAL CONDUCTIVITY= .7251E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 201.881  
 WITH BLOCK TEMPS OF 209.415 AND 194.347 DELT= 15.068  
 HERE TOTAL HEAT FLOW= .7645E+00 AND SPEC HEAT FLOW= .6600E+00( 86. PCT)  
 Q/T.OELT(TOTAL)= .2513E-03 (EMPTY PROBE)= .3437E-04 (SPECIMEN)= .2170E-03  
 HEATER RESISTANCE= 199.215 AND HEATER VOLTAGE= .1234E+02

# APPENDIX (continued)

## Specimen 25-A

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 25-A, 6/14/83, 1205

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
17.4400	87.5000	504.30	5.	2.	2.0380	273.20	0.00	.5400

THERMAL CONDUCTIVITY=	.8628E+00	UNCERTAINTY=	4. PERCENT
AT A MEAN TEMP OF	288.113		
WITH BLOCK TEMPS OF	299.470 AND	276.756	DELT= 22.714
HERE TOTAL HEAT FLOW=	.1526E+01	AND SPEC HEAT FLOW=	.1211E+01( 79. PCT)
Q/T, DELT(TOTAL)=	.2332E-03 (EMPTY PROBE)=	.4808E-04	(SPECIMEN)= .1851E-03
HEATER RESISTANCE=	199.314	AND HEATER VOLTAGE=	.1744E+02

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# APPENDIX (continued)

## Specimen 26

### --- THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 26,6/15/83,1004

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
1.9979	10.0600	40.00	1.	2.	2.0880	4.02	-.33	.5400

THERMAL CONDUCTIVITY= .9926E-01      UNCERTAINTY= 3. PERCENT  
 AT A MEAN TEMP OF 5.901  
 WITH BLOCK TEMPS OF 7.432 AND 4.371 DELT= 3.061  
 HERE TOTAL HEAT FLOW= .2010E-01 AND SPEC HEAT FLOW= .1927E-01( 96. PCT)  
 O/T.DELT(TOTAL)= .1113E-02 (EMPTY PROBE)= .4612E-04 (SPECIMEN)= .1067E-02  
 HEATER RESISTANCE= 199.599 AND HEATER VOLTAGE= .1998E+01

### --- THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 26,6/15/83,1030

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
11.0648	55.7000	640.00	1.	2.	2.0880	4.02	-.33	.5400

THERMAL CONDUCTIVITY= .2161E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 29.615  
 WITH BLOCK TEMPS OF 50.099 AND 9.131 DELT= 40.967  
 HERE TOTAL HEAT FLOW= .6163E+00 AND SPEC HEAT FLOW= .5615E+00( 91. PCT)  
 O/T.DELT(TOTAL)= .5080E-03 (EMPTY PROBE)= .4519E-04 (SPECIMEN)= .4628E-03  
 HEATER RESISTANCE= 199.650 AND HEATER VOLTAGE= .1106E+02

### --- THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 26,6/15/83,1100

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
17.9290	90.2000	1280.00	1.	2.	2.0880	4.02	-.33	.5400

THERMAL CONDUCTIVITY= .2953E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 53.024  
 WITH BLOCK TEMPS OF 91.905 AND 14.143 DELT= 77.762  
 HERE TOTAL HEAT FLOW= .1617E+01 AND SPEC HEAT FLOW= .1456E+01( 90. PCT)  
 O/T.DELT(TOTAL)= .3922E-03 (EMPTY PROBE)= .3903E-04 (SPECIMEN)= .3532E-03  
 HEATER RESISTANCE= 198.769 AND HEATER VOLTAGE= .1793E+02

### --- THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 26,6/15/83,1330

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
9.9520	50.0500	307.00	3.	2.	2.0880	76.00	0.00	.5400

THERMAL CONDUCTIVITY= .4104E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 85.863  
 WITH BLOCK TEMPS OF 94.450 AND 77.275 DELT= 17.175  
 HERE TOTAL HEAT FLOW= .4981E+00 AND SPEC HEAT FLOW= .4470E+00( 90. PCT)  
 O/T.DELT(TOTAL)= .3378E-03 (EMPTY PROBE)= .3467E-04 (SPECIMEN)= .3031E-03  
 HEATER RESISTANCE= 198.841 AND HEATER VOLTAGE= .9952E+01

# APPENDIX (continued)

## Specimen 26

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 26,6/15/83,1900

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
17.6407	88.5000	503.40	5.	2.	2.0880	273.20	0.00	.5400

THERMAL CONDUCTIVITY= .8674E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 288.174  
 WITH BLOCK TEMPS OF 299.511 AND 276.838 DELT= 22.674  
 HERE TOTAL HEAT FLOW= .1561E+01 AND SPEC HEAT FLOW= .1247E+01( 80. PCT)  
 Q/T,DELT(TOTAL)= .2389E-03 (EMPTY PROBE)= .4807E-04 (SPECIMEN)= .1909E-03  
 HEATER RESISTANCE= 199.330 AND HEATER VOLTAGE= .1764E+02

### THERMAL CONDUCTIVITY DATA FOR EPOX/FIB STRAP 26,6/15/83,1600

HTR VOLT	HTR CURR	DELTA E	BTH	PRB	DIAMETER	TEMP	DELE ZERO	DELTA X
12.5503	63.0000	321.68	4.	2.	2.0880	192.00	0.00	.5400

THERMAL CONDUCTIVITY= .7153E+00      UNCERTAINTY= 4. PERCENT  
 AT A MEAN TEMP OF 201.987  
 WITH BLOCK TEMPS OF 209.546 AND 194.427 DELT= 15.118  
 HERE TOTAL HEAT FLOW= .7907E+00 AND SPEC HEAT FLOW= .6857E+00( 87. PCT)  
 Q/T,DELT(TOTAL)= .2589E-03 (EMPTY PROBE)= .3437E-04 (SPECIMEN)= .2246E-03  
 HEATER RESISTANCE= 199.211 AND HEATER VOLTAGE= .1255E+02

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